09/890793

PATENT COOPERATION TREATY

5000

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

From the INTERNATIONAL BUREAU

To:

BARDO, Julian, Eason
Abel & Imray
20 Red Lion Street
London WC1R 4PQ
ROYAUME-UNI

Date of mailing (day/month/year) 18 October 2001 (18.10.01)	
Applicant's or agent's file reference JEB/MPC/4745 WO	**IMPORTANT NOTIFICATION**
International application No. PCT/GB00/00600	**International filing date** (day/month/year) 18 February 2000 (18.02.00)

1. The following indications appeared on record concerning:

[X] the applicant [ ] the inventor [ ] the agent [ ] the common representative

Name and Address	State of Nationality	State of Residence
THE UNIVERSITY OF BATH Claverton Down Bath BA2 7AY United Kingdom	GB	GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

CORRECTED VERSION

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[X] the person [ ] the name [ ] the address [ ] the nationality [ ] the residence

Name and Address	State of Nationality	State of Residence
BLAZEPHOTONICS LIMITED Finance Office University of Bath The Avenue Claverton Down Bath BA2 7AY United Kingdom	GB	GB
	Telephone No.	
	Facsimile No.	
	Teleprinter No.	

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[X] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer Idhir BRITEL
Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

PA NT COOPERATION TREAT

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

To:

BARDO, Julian, Eason
Abel & Imray
20 Red Lion Street
London WC1R 4PQ
ROYAUME-UNI

Date of mailing (day/month/year)
22 June 2001 (22.06.01)

Applicant's or agent's file reference
JEB/MPC/4745 WO

IMPORTANT NOTIFICATION

International application No.
PCT/GB00/00600

International filing date (day/month/year)
18 February 2000 (18.02.00)

1. The following indications appeared on record concerning:

[X] the applicant [ ] the inventor [ ] the agent [ ] the common representative

Name and Address
THE UNIVERSITY OF BATH
Claverton Down
Bath BA2 7AY
United Kingdom

State of Nationality: GB
State of Residence: GB
Telephone No.:
Facsimile No.:
Teleprinter No.:

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[ ] the person [X] the name [X] the address [ ] the nationality [ ] the residence

Name and Address
BALZE PHOTONICS LIMITED
Finance Office
University of Bath
The Avenue Claverton Down
Bath BA2 7AY
United Kingdom

State of Nationality: GB
State of Residence: GB
Telephone No.:
Facsimile No.:
Teleprinter No.:

3. Further observations, if necessary:
The person in Box 1 has transferred the assignment to the person in Box 2.

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[X] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Facsimile No.: (41-22) 740.14.35

Authorized officer
Lazar Joseph Panakal
Telephone No.: (41-22) 338.83.38

PA NT COOPERATION TREAT

CORRECTED VERSION

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

From the INTERNATIONAL BUREAU

To:

BARDO, Julian, Eason
Abel & Imray
20 Red Lion Street
London WC1R 4PQ
ROYAUME-UNI

Date of mailing (day/month/year)
17 July 2001 (17.07.01)

Applicant's or agent's file reference
JEB/MPC/4745 WO

IMPORTANT NOTIFICATION

International application No.
PCT/GB00/00600

International filing date (day/month/year)
18 February 2000 (18.02.00)

1. The following indications appeared on record concerning:

[X] the applicant [ ] the inventor [ ] the agent [ ] the common representative

Name and Address
THE UNIVERSITY OF BATH
Claverton Down
Bath BA2 7AY
United Kingdom

State of Nationality: GB
State of Residence: GB
Telephone No.:
Facsimile No.:
Teleprinter No.:

2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[X] the person [ ] the name [ ] the address [ ] the nationality [ ] the residence

Name and Address
BALZEPHOTONICS LIMITED
Finance Office
University of Bath
The Avenue
Claverton Down
Bath BA2 7AY
United Kingdom

State of Nationality: GB
State of Residence: GB
Telephone No.:
Facsimile No.:
Teleprinter No.:

3. Further observations, if necessary:

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[X] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Facsimile No.: (41-22) 740.14.35

Authorized officer
Anman QIU
Telephone No.: (41-22) 338.83.38

PA NT COOPERATION TREAT

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 02 November 2000 (02.11.00)	
International application No. PCT/GB00/00600	**Applicant's or agent's file reference** JEB/MPC/4745 WO
International filing date (day/month/year) 18 February 2000 (18.02.00)	**Priority date** (day/month/year) 19 February 1999 (19.02.99)
Applicant RUSSELL, Philip, St. John et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

19 September 2000 (19.09.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer Juan Cruz
Facsimile No.: (41-22) 740.14.35	Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
4745WO/JEB/MPC		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/00600	18/02/2000	19/02/1999
International Patent Classification (IPC) or national classification and IPC G02B6/17		
Applicant THE UNIVERSITY OF BATH et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 9 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☒ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
19/09/2000	27.03.01
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Gaukel, G Telephone No. +49 89 2399 2752

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/00600

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
Description, pages:

1-19	as originally filed

Claims, No.:

1-43	as originally filed

Drawings, sheets:

1/9-9/9	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   - ☐ the description, pages:
   - ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

(Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

☐ the entire international application.

☒ claims Nos. 3,9,11-19,21-25,29-33,43.

because:

☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. 3,9,11-19,21-25,29-33,43 are so unclear that no meaningful opinion could be formed (*specify*):
see separate sheet

☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

☐ no international search report has been established for the said claims Nos. .

2. A meaningful international preliminary examination cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

☐ the written form has not been furnished or does not comply with the standard.

☐ the computer readable form has not been furnished or does not comply with the standard.

IV. Lack of unity of invention

1. In response to the invitation to restrict or pay additional fees the applicant has:

☐ restricted the claims.

☐ paid additional fees.

☐ paid additional fees under protest.

☐ neither restricted nor paid additional fees.

2. ☒ This Authority found that the requirement of unity of invention is not complied and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

☐ complied with.

☒ not complied with for the following reasons:
see separate sheet

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

☒ all parts.

☐ the parts relating to claims Nos. .

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	
	No:	Claims	1,2, 5-8,10, 20,26-28
Inventive step (IS)	Yes:	Claims	4, 34-42
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1,2,4-8,10,20,26-28,34-42
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

see separate sheet

Concerning **section III**:

see section VIII, point 2

Concerning **section IV**:

1. It appears that the subject-matter of claim 37 refers to a particular production method not related to the essential symmetry aspect expressed, as far as understood, in claims 1 and 20, but to a way of producing particular hole diameters during drawing of a fibre. Therefore, claim 37 lacks unity of invention with regard to claim 1 and 20.

   However, in order to meet the tight time limits, the applicant will not be invited to pay additional examination fees.

Concerning section V:

1. In the light of the severe clarity objections (see section VIII), only a provisional opinion can be given.
   As is also acknowledged by the applicant in the present description, photonic crystal fibres are known in the art. Therefore, fibres comprising a bulk material having an arrangement of longitudinal holes (or voids) and a guiding core are known in the art (see, for example, D1: US 5,802,236, abstract, figs. 1 and 2 & corresponding text). It is also known from D1 that non-periodic optical fibres form part of the state-of-the-art. "Non-periodic" is understood as "at-most two-fold symmetry" since there is no symmetry at all (see col.3, lines 45 to 52).
   Moreover, triangular and hexagonal patterns are also known for the arrangement of the voids, as well as the arrangement of a "defect" site, either bulk or hollow filled with liquid, in the core or within the "holey" part of the fibre to induce waveguiding.
   Therefore, it appears that D1 anticipates the subject-matters of claims 1, 2, 5 to 10 is understood as defining no symmetry or the above cited symmetric structures.

This applies also to the subject-matter of claim 20, as far as understandable (see D1, col.6, line 36 to col.7, line 53) and claim 28, since the number of canes forming the core appears to be smaller that forming the cladding.
Moreover, it appears that D1 also discloses the features of claims 26 and 27 as regards a "non-symmetric" arrangement of canes about the central axis.

3. Taking into account the description and the figures, it appears that the gist of the application relates to a birefringent fibre. The birefringence is achieved via particular structures inducing either form or stress birefringence, the corresponding structural features are apparently the symmetric distribution of "different" voids adjacent the guiding core, the symmetry being with regard to an axis perpendicular to the longitudinal axis of the core. Or in simpler terms, the cladding portions inducing birefringence oppose each other.

It appears to be essential, to define these features responsible for the **bi**refringence since it a appears that even with a one-fold or two-fold rotational symmetry of the structure with regard to the axis of the guiding core, birefringence is not necessarily achieved.

Taking into account such a clarification, the subject-matter of claims 4 and 34 to 42 (correponding method) do not appear to be rendered obvious by the prior art.
A claim clearly defining the structures as disclosed would appear to be novel and inventive.

Concerning **section VII**:

The features of claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).
Independent claims 1 and 18 are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combi- nation from the prior art (document D1) being placed in a preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in a characterising part (Rule 6.3(b)(ii) PCT).

Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the documents D1 and D2 (numbered according the order of the Search Report) documents identified therein.

Concerning **section VIII**:

1. It is not clear from the wording of claim 1, as well as from that of claim 20, which feature the expression "at-most-two-fold rotational symmetry" should specify, in particular in view of the following phrase referring to a lack of symmetry. Therefore, this passage of the claim cannot be understood at present. It is however understood that the claimed fibre shall be birefringent, this statement however gives only the intended result and not the related structural features.
In this respect, attention is drawn to claim 34 also referring to a "lack of rotational symmetry".

In addition, it is noted that the reference to "a longitudinal axis" cannot further specify the symmetry, if there were symmetry, since it is completely unclear which "longitudinal axis" is meant.

Furthermore, the following claims either refer to a symmetry of the **fibre** with regard to the centre of the fibre or the arrangement of **holes** about an axis parallel to the longitudinal axis of the fibre. It is not clear whether both conditions can be met at a time and therefore, it appears that an internal contradiction occurs.

2. Claims 3, 9, 11 to 19 refer to the intended results and effects, like "lack of higher symmetry" and thus do not define the claimed subject-matter in technical terms as required by Art.6. It is thus not clear which structural features are intended to be claimed.
This applies also to method claims 20 to 25, 29, 32 and 33. In particular, it is not clear how the desired "at-most-two-fold rotational symmetry" and the birfringence can achieved via a not further specified drawing step (claim 20).

At present, it is not obvious which features are intended to be defined by claims 21 to 25, 29, 32 and 33.
In addition, it is noted that the reference to "sites having a .... symmetry" is obscure and it is not evident which feature could be meant (claims 30, 31).

Moreover, claim 43 specifies an "at most two-fold symmetry about any of the longitudinal axes". It is however completely unclear which structure is intended to be defined by the that expression.

PCT

REQUEST

The undersigned requests that the present international application be processed according to the Patent Cooperation Treaty.

For receiving Office use only

International Application No.

International Filing Date

Name of receiving Office and "PCT International Application"

Applicant's or agent's file reference *(if desired) (12 characters maximum)* JEB/MPC/4745 WO

Box No. I TITLE OF INVENTION

Improvements in or relating to photonic crystal fibres

Box No. II APPLICANT

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

The University of Bath
Claverton Down
Bath
BA2 7AY
United Kingdom

☐ This person is also inventor.

Telephone No.

Facsimile No.

Teleprinter No.

State *(that is, country)* of nationality: GB

State *(that is, country)* of residence: GB

This person is applicant for the purposes of: ☐ all designated States ☒ all designated States except the United States of America ☐ the United States of America only ☐ the States indicated in the Supplemental Box

Box No. III FURTHER APPLICANT(S) AND/OR (FURTHER) INVENTOR(S)

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

Russell, Philip St. John
Shepherds Mead
Southstoke
Bath BA2 7EB
United Kingdom

This person is:

☐ applicant only

☒ applicant and inventor

☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality: GB

State *(that is, country)* of residence: GB

This person is applicant for the purposes of: ☐ all designated States ☐ all designated States except the United States of America ☒ the United States of America only ☐ the States indicated in the Supplemental Box

☒ Further applicants and/or (further) inventors are indicated on a continuation sheet.

Box No. IV AGENT OR COMMON REPRESENTATIVE; OR ADDRESS FOR CORRESPONDENCE

The person identified below is hereby/has been appointed to act on behalf of the applicant(s) before the competent International Authorities as: ☒ agent ☐ common representative

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country.)*

BARDO, Julian Eason
Abel & Imray
20 Red Lion Street
London
WC1R 4PQ
United Kingdom

Telephone No. 020 7242 9984

Facsimile No. 020 7242 9989

Teleprinter No.

☐ **Address for correspondence:** Mark this check-box where no agent or common representative is/has been appointed and the space above is used instead to indicate a special address to which correspondence should be sent.

Continuation of Box No. III FUR[redacted] APPLICANT(S) AND/OR (FURTHER) IN[redacted]TOR(S)

If none of the following sub-boxes is used, this sheet should not be included in the request.

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

Birks, Timothy Adam
14 Horsecombe Brow
Combe Down
Bath BA2 5QY
United Kingdom

This person is:
- ☐ applicant only
- ☒ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality: GB

State *(that is, country)* of residence: GB

This person is applicant for the purposes of:
- ☐ all designated States
- ☐ all designated States except the United States of America
- ☒ the United States of America only
- ☐ the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

Knight, Jonathan Cave
Canteen Cottage
Canteen Lane
Wellow
Bath
United Kingdom

This person is:
- ☐ applicant only
- ☒ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality: GB

State *(that is, country)* of residence: GB

This person is applicant for the purposes of:
- ☐ all designated States
- ☐ all designated States except the United States of America
- ☒ the United States of America only
- ☐ the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

This person is:
- ☐ applicant only
- ☐ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality:

State *(that is, country)* of residence:

This person is applicant for the purposes of:
- ☐ all designated States
- ☐ all designated States except the United States of America
- ☐ the United States of America only
- ☐ the States indicated in the Supplemental Box

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

This person is:
- ☐ applicant only
- ☐ applicant and inventor
- ☐ inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality:

State *(that is, country)* of residence:

This person is applicant for the purposes of:
- ☐ all designated States
- ☐ all designated States except the United States of America
- ☐ the United States of America only
- ☐ the States indicated in the Supplemental Box

☐ Further applicants and/or (further) inventors are indicated on another continuation sheet.

Box No.V DESIGNATION OF STATES

The following designations are hereby made under Rule 4.9(a) *(mark the applicable check-boxes; at least one must be marked)*:

Regional Patent

- ☒ AP **ARIPO Patent:** GH Ghana, GM Gambia, KE Kenya, LS Lesotho, MW Malawi, SD Sudan, SL Sierra Leone, SZ Swaziland, TZ United Republic of Tanzania, UG Uganda, ZW Zimbabwe, and any other State which is a Contracting State of the Harare Protocol and of the PCT
- ☒ EA **Eurasian Patent:** AM Armenia, AZ Azerbaijan, BY Belarus, KG Kyrgyzstan, KZ Kazakhstan, MD Republic of Moldova, RU Russian Federation, TJ Tajikistan, TM Turkmenistan, and any other State which is a Contracting State of the Eurasian Patent Convention and of the PCT
- ☒ EP **European Patent:** AT Austria, BE Belgium, CH and LI Switzerland and Liechtenstein, CY Cyprus, DE Germany, DK Denmark, ES Spain, FI Finland, FR France, GB United Kingdom, GR Greece, IE Ireland, IT Italy, LU Luxembourg, MC Monaco, NL Netherlands, PT Portugal, SE Sweden, and any other State which is a Contracting State of the European Patent Convention and of the PCT
- ☒ OA **OAPI Patent:** BF Burkina Faso, BJ Benin, CF Central African Republic, CG Congo, CI Côte d'Ivoire, CM Cameroon, GA Gabon, GN Guinea, GW Guinea-Bissau, ML Mali, MR Mauritania, NE Niger, SN Senegal, TD Chad, TG Togo, and any other State which is a member State of OAPI and a Contracting State of the PCT *(if other kind of protection or treatment desired, specify on dotted line)* .....

National Patent *(if other kind of protection or treatment desired, specify on dotted line)*:

- ☒ AE United Arab Emirates
- ☒ AL Albania
- ☒ AM Armenia
- ☒ AT Austria
- ☒ AU Australia
- ☒ AZ Azerbaijan
- ☒ BA Bosnia and Herzegovina
- ☒ BB Barbados
- ☒ BG Bulgaria
- ☒ BR Brazil
- ☒ BY Belarus
- ☒ CA Canada
- ☒ CH and LI Switzerland and Liechtenstein
- ☒ CN China
- ☒ CR Costa Rica
- ☒ CU Cuba
- ☒ CZ Czech Republic
- ☒ DE Germany
- ☒ DK Denmark
- ☒ DM Dominica
- ☒ EE Estonia
- ☒ ES Spain
- ☒ FI Finland
- ☒ GB United Kingdom
- ☒ GD Grenada
- ☒ GE Georgia
- ☒ GH Ghana
- ☒ GM Gambia
- ☒ HR Croatia
- ☒ HU Hungary
- ☒ ID Indonesia
- ☒ IL Israel
- ☒ IN India
- ☒ IS Iceland
- ☒ JP Japan
- ☒ KE Kenya
- ☒ KG Kyrgyzstan
- ☒ KP Democratic People's Republic of Korea
- ☒ KR Republic of Korea
- ☒ KZ Kazakhstan
- ☒ LC Saint Lucia
- ☒ LK Sri Lanka
- ☒ LR Liberia
- ☒ LS Lesotho
- ☒ LT Lithuania
- ☒ LU Luxembourg
- ☒ LV Latvia
- ☒ MA Morocco
- ☒ MD Republic of Moldova
- ☒ MG Madagascar
- ☒ MK The former Yugoslav Republic of Macedonia
- ☒ MN Mongolia
- ☒ MW Malawi
- ☒ MX Mexico
- ☒ NO Norway
- ☒ NZ New Zealand
- ☒ PL Poland
- ☒ PT Portugal
- ☒ RO Romania
- ☒ RU Russian Federation
- ☒ SD Sudan
- ☒ SE Sweden
- ☒ SG Singapore
- ☒ SI Slovenia
- ☒ SK Slovakia
- ☒ SL Sierra Leone
- ☒ TJ Tajikistan
- ☒ TM Turkmenistan
- ☒ TR Turkey
- ☒ TT Trinidad and Tobago
- ☒ TZ United Republic of Tanzania
- ☒ UA Ukraine
- ☒ UG Uganda
- ☒ US United States of America
- ☒ UZ Uzbekistan
- ☒ VN Viet Nam
- ☒ YU Yugoslavia
- ☒ ZA South Africa
- ☒ ZW Zimbabwe

Check-boxes reserved for designating States which have become party to the PCT after issuance of this sheet:

- ☒ Any other state which has become a party to the PCT after issuance of this sheet.
- ☐

Precautionary Designation Statement: In addition to the designations made above, the applicant also makes under Rule 4.9(b) all other designations which would be permitted under the PCT except any designation(s) indicated in the Supplemental Box as being excluded from the scope of this statement. The applicant declares that those additional designations are subject to confirmation and that any designation which is not confirmed before the expiration of 15 months from the priority date is to be regarded as withdrawn by the applicant at the expiration of that time limit. *(Confirmation (including fees) must reach the receiving Office within the 15-month time limit.)*

Supplemental Box *If the Supplemental Box is not used, this sheet should not be included in the request.*

1. If, in any of the Boxes, the space is insufficient to furnish all the information: in such case, write "Continuation of Box No. ..." [indicate the number of the Box] and furnish the information in the same manner as required according to the captions of the Box in which the space was insufficient, in particular:

*(i) **if more than two persons are involved as applicants and/or inventors** and no "continuation sheet" is available: in such case, write "Continuation of Box No. III" and indicate for each additional person the same type of information as required in Box No. III. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below;*

*(ii) if, in Box No. II or in any of the sub-boxes of Box No. III, the indication **"the States indicated in the Supplemental Box"** is checked: in such case, write "Continuation of Box No. II" or "Continuation of Box No. III" or "Continuation of Boxes No. II and No. III" (as the case may be), indicate the name of the applicant(s) involved and, next to (each) such name, the State(s) (and/or, where applicable, ARIPO, Eurasian, European or OAPI patent) for the purposes of which the named person is applicant;*

*(iii) if, in Box No. II or in any of the sub-boxes of Box No. III, **the inventor or the inventor/applicant is not inventor for the purposes of all designated States or for the purposes of the United States of America**: in such case, write "Continuation of Box No. II" or "Continuation of Box No. III" or "Continuation of Boxes No. II and No. III" (as the case may be), indicate the name of the inventor(s) and, next to (each) such name, the State(s) (and/or, where applicable, ARIPO, Eurasian, European or OAPI patent) for the purposes of which the named person is inventor;*

*(iv) if, in addition to the agent(s) indicated in Box No. IV, there are **further agents**: in such case, write "Continuation of Box No. IV" and indicate for each further agent the same type of information as required in Box No. IV;*

*(v) if, in Box No. V, the name of any State (or OAPI) is accompanied by the indication "**patent of addition**," or "**certificate of addition**," or if, in Box No. V, the name of the United States of America is accompanied by an indication "**continuation**" or "**continuation-in-part**": in such case, write "Continuation of Box No. V" and the name of each State involved (or OAPI), and after the name of each such State (or OAPI), the number of the parent title or parent application and the date of grant of the parent title or filing of the parent application;*

*(vi) if, in Box No. VI, there are **more than three earlier applications whose priority is claimed**: in such case, write "Continuation of Box No. VI" and indicate for each additional earlier application the same type of information as required in Box No. VI;*

*(vii) if, in Box No. VI, **the earlier application is an ARIPO application**: in such case, write "Continuation of Box No. VI", specify the number of the item corresponding to that earlier application and indicate at least one country party to the Paris Convention for the Protection of Industrial Property or one Member of the World Trade Organization for which that earlier application was filed.*

*2. If, with regard to the **precautionary designation statement** contained in Box No. V, the applicant wishes to exclude any State(s) from the scope of that statement: in such case, write "Designation(s) excluded from precautionary designation statement" and indicate the name or two-letter code of each State so excluded.*

*3. If the applicant claims, in respect of any designated Office, the benefits of provisions of the national law concerning **non-prejudicial disclosures or exceptions to lack of novelty**: in such case, write "Statement concerning non-prejudicial disclosures or exceptions to lack of novelty" and furnish that statement below.*

Continuation of Box No. IV

Darby,	David	Thomas	
Coulson,	Antony	John	
Barry,	Patrick	James	
Senior,	Janet		
Mair,	Richard	Douglas	
Humphreys,	Ceris	Anne	
Carter,	Caroline	Ann	
Nettleton,	John	Victor	
Lowther,	Deborah	Jane	
Legg,	Cyrus	James	Grahame
Pearson,	James	Ginn	

of ABEL & IMRAY
20 Red Lion Street
London
WC1R 4PQ
United Kingdom

Telephone Number:	020 7242 9984
Facsimile Number:	020 7242 9989
Telex Address:	24621 IMRAY G
Telegraphic Address;	Patentable London WC1

Box No. VI PRIORITY CLAIM ☐ Further priority claims are indicated in the Supplemental Box.

Filing date of earlier application (day/month/year)	Number of earlier application	Where earlier application is: national application: country	regional application:* regional Office	international application: receiving Office
item (1) 19/02/99	9903918.2	GB		
item (2) 19/02/99	9903923.2	GB		
item (3)				

☒ The receiving Office is requested to prepare and transmit to the International Bureau a certified copy of the earlier application(s) *(only if the earlier application was filed with the Office which for the purposes of the present international application is the receiving Office)* identified above as item(s): _____

* *Where the earlier application is an ARIPO application, it is mandatory to indicate in the Supplemental Box at least one country party to the Paris Convention for the Protection of Industrial Property for which that earlier application was filed (Rule 4.10(b)(ii)). See Supplemental Box.*

Box No. VII INTERNATIONAL SEARCHING AUTHORITY

Choice of International Searching Authority (ISA) *(if two or more International Searching Authorities are competent to carry out the international search, indicate the Authority chosen; the two-letter code may be used)* : ISA /

Request to use results of earlier search; reference to that search *(if an earlier search has been carried out by or requested from the International Searching Authority):*
Date *(day/month/year)* Number Country *(or regional Office)*

Box No. VIII CHECK LIST; LANGUAGE OF FILING

This international application contains the following **number of sheets**:

request	:	5
description (excluding sequence listing part)	:	19
claims	:	7
abstract	:	1
drawings	:	9
sequence listing part of description	:	
Total number of sheets	:	41

This international application is **accompanied by** the item(s) marked below:

1. ☐ fee calculation sheet
2. ☐ separate signed power of attorney
3. ☐ copy of general power of attorney; reference number, if any:
4. ☐ statement explaining lack of signature
5. ☐ priority document(s) identified in Box No. VI as item(s):
6. ☐ translation of international application into (language):
7. ☐ separate indications concerning deposited microorganism or other biological material
8. ☐ nucleotide and/or amino acid sequence listing in computer readable form
9. ☐ other *(specify)*:

Figure of the drawings which should accompany the abstract: 6

Language of filing of the international application: English

Box No. IX SIGNATURE OF APPLICANT OR AGENT

Next to each signature, indicate the name of the person signing and the capacity in which the person signs (if such capacity is not obvious from reading the request).

C M-Leggs.
CYRUS JAMES GRAHAME LEIGH-
FURTHER AGENT (SEE BOX IV)

for Julian Eason BARDO

For receiving Office use only

1. Date of actual receipt of the purported international application:
2. Drawings: ☐ received: ☐ not received:
3. Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application:
4. Date of timely receipt of the required corrections under PCT Article 11(2):
5. International Searching Authority (if two or more are competent): ISA /
6. ☐ Transmittal of search copy delayed until search fee is paid.

For International Bureau use only

Date of receipt of the record copy by the International Bureau:

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
4745WO/JEB/MPC		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB00/00600	18/02/2000	19/02/1999
International Patent Classification (IPC) or national classification and IPC G02B6/17		
Applicant THE UNIVERSITY OF BATH et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 9 sheets, including this cover sheet.

   ☐ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☒ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☒ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☒ Certain defects in the international application
   - VIII ☒ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
19/09/2000	27.03.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Gaukel, G Telephone No. +49 89 2399 2752

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/GB00/00600

I. Basis of th report

1. This report has been drawn on the basis of *(substitute sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments (Rules 70.16 and 70.17).)*:
Description, pages:

1-19 as originally filed

Claims, No.:

1-43 as originally filed

Drawings, sheets:

1/9-9/9 as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

These elements were available or furnished to this Authority in the following language: , which is:

- ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
- ☐ the language of publication of the international application (under Rule 48.3(b)).
- ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

- ☐ contained in the international application in written form.
- ☐ filed together with the international application in computer readable form.
- ☐ furnished subsequently to this Authority in written form.
- ☐ furnished subsequently to this Authority in computer readable form.
- ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
- ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:

☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

III. Non-establishment of opinion with regard to novelty, inventive step and industrial applicability

1. The questions whether the claimed invention appears to be novel, to involve an inventive step (to be non-obvious), or to be industrially applicable have not been examined in respect of:

   ☐ the entire international application.

   ☒ claims Nos. 3,9,11-19,21-25,29-33,43.

because:

   ☐ the said international application, or the said claims Nos. relate to the following subject matter which does not require an international preliminary examination (*specify*):

   ☒ the description, claims or drawings (*indicate particular elements below*) or said claims Nos. 3,9,11-19,21-25,29-33,43 are so unclear that no meaningful opinion could be formed (*specify*):
   see separate sheet

   ☐ the claims, or said claims Nos. are so inadequately supported by the description that no meaningful opinion could be formed.

   ☐ no international search report has been established for the said claims Nos. .

2. A meaningful international preliminary examination report cannot be carried out due to the failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions:

   ☐ the written form has not been furnished or does not comply with the standard.

   ☐ the computer readable form has not been furnished or does not comply with the standard.

IV. Lack of unity of invention

1. In response to the invitation to restrict or pay additional fees the applicant has:

   ☐ restricted the claims.

☐ paid additional fees.

☐ paid additional fees under protest.

☐ neither restricted nor paid additional fees.

2. ☒ This Authority found that the requirement of unity of invention is not complied and chose, according to Rule 68.1, not to invite the applicant to restrict or pay additional fees.

3. This Authority considers that the requirement of unity of invention in accordance with Rules 13.1, 13.2 and 13.3 is

☐ complied with.

☒ not complied with for the following reasons:
see separate sheet

4. Consequently, the following parts of the international application were the subject of international preliminary examination in establishing this report:

☒ all parts.

☐ the parts relating to claims Nos. .

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	
	No:	Claims	1,2, 5-8,10, 20,26-28
Inventive step (IS)	Yes:	Claims	4, 34-42
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1,2,4-8,10,20,26-28,34-42
	No:	Claims	

2. Citations and explanations
see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:

see separate sheet

Concerning **section III**:

see section VIII, point 2

Concerning **section IV**:

1. It appears that the subject-matter of claim 37 refers to a particular production method not related to the essential symmetry aspect expressed, as far as understood, in claims 1 and 20, but to a way of producing particular hole diameters during drawing of a fibre. Therefore, claim 37 lacks unity of invention with regard to claim 1 and 20.

However, in order to meet the tight time limits, the applicant will not be invited to pay additional examination fees.

Concerning section V:

1. In the light of the severe clarity objections (see section VIII), only a provisional opinion can be given.
As is also acknowledged by the applicant in the present description, photonic crystal fibres are known in the art. Therefore, fibres comprising a bulk material having an arrangement of longitudinal holes (or voids) and a guiding core are known in the art (see, for example, D1: US 5,802,236, abstract, figs. 1 and 2 & corresponding text). It is also known from D1 that non-periodic optical fibres form part of the state-of-the-art. "Non-periodic" is understood as "at-most two-fold symmetry" since there is no symmetry at all (see col.3, lines 45 to 52).
Moreover, triangular and hexagonal patterns are also known for the arrangement of the voids, as well as the arrangement of a "defect" site, either bulk or hollow filled with liquid, in the core or within the "holey" part of the fibre to induce waveguiding.
Therefore, it appears that D1 anticipates the subject-matters of claims 1, 2, 5 to 10 is understood as defining no symmetry or the above cited symmetric structures.

This applies also to the subject-matter of claim 20, as far as understandable (see D1, col.6, line 36 to col.7, line 53) and claim 28, since the number of canes forming the core appears to be smaller that forming the cladding.
Moreover, it appears that D1 also discloses the features of claims 26 and 27 as regards a "non-symmetric" arrangement of canes about the central axis.

3. Taking into account the description and the figures, it appears that the gist of the application relates to a birefringent fibre. The birefringence is achieved via particular structures inducing either form or stress birefringence, the corresponding structural features are apparently the symmetric distribution of "different" voids adjacent the guiding core, the symmetry being with regard to an axis perpendicular to the longitudinal axis of the core. Or in simpler terms, the cladding portions inducing birefringence oppose each other.

It appears to be essential, to define these features responsible for the **bi**refringence since it a appears that even with a one-fold or two-fold rotational symmetry of the structure with regard to the axis of the guiding core, birefringence is not necessarily achieved.

Taking into account such a clarification, the subject-matter of claims 4 and 34 to 42 (correponding method) do not appear to be rendered obvious by the prior art.
A claim clearly defining the structures as disclosed would appear to be novel and inventive.

Concerning **section VII**:

The features of claims are not provided with reference signs placed in parentheses (Rule 6.2(b) PCT).
Independent claims 1 and 18 are not in the two-part form in accordance with Rule 6.3(b) PCT, which in the present case would be appropriate, with those features known in combi- nation from the prior art (document D1) being placed in a preamble (Rule 6.3(b)(i) PCT) and with the remaining features being included in a characterising part (Rule 6.3(b)(ii) PCT).

Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in the documents D1 and D2 (numbered according the order of the Search Report) documents identified therein.

Concerning **section VIII**:

1. It is not clear from the wording of claim 1, as well as from that of claim 20, which feature the expression "at-most-two-fold rotational symmetry" should specify, in particular in view of the following phrase referring to a lack of symmetry. Therefore, this passage of the claim cannot be understood at present. It is however understood that the claimed fibre shall be birefringent, this statement however gives only the intended result and not the related structural features.
In this respect, attention is drawn to claim 34 also referring to a "lack of rotational symmetry".

In addition, it is noted that the reference to "a longitudinal axis" cannot further specify the symmetry, if there were symmetry, since it is completely unclear which "longitudinal axis" is meant.

Furthermore, the following claims either refer to a symmetry of the **fibre** with regard to the centre of the fibre or the arrangement of **holes** about an axis parallel to the longitudinal axis of the fibre. It is not clear whether both conditions can be met at a time and therefore, it appears that an internal contradiction occurs.

2. Claims 3, 9, 11 to 19 refer to the intended results and effects, like "lack of higher symmetry" and thus do not define the claimed subject-matter in technical terms as required by Art.6. It is thus not clear which structural features are intended to be claimed.
This applies also to method claims 20 to 25, 29, 32 and 33. In particular, it is not clear how the desired "at-most-two-fold rotational symmetry" and the birfringence can achieved via a not further specified drawing step (claim 20).

At present, it is not obvious which features are intended to be defined by claims 21 to 25, 29, 32 and 33.
In addition, it is noted that the reference to "sites having a .... symmetry" is obscure and it is not evident which feature could be meant (claims 30, 31).

Moreover, claim 43 specifies an "at most two-fold symmetry about any of the longitudinal axes". It is however completely unclear which structure is intended to be defined by the that expression.

ENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
JEB/MPC/4745 WO		
International application No.	International filing date *(day/month/year)*	(Earliest) Priority Date *(day/month/year)*
PCT/GB 00/ 00600	18/02/2000	19/02/1999
Applicant		
THE UNIVERSITY OF BATH et al.		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language,** the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

   [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

   [ ] contained in the international application in written form.

   [ ] filed together with the international application in computer readable form.

   [ ] furnished subsequently to this Authority in written form.

   [ ] furnished subsequently to this Authority in computer readble form.

   [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

   [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established by this Authority to read as follows:

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.

   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 6

   [X] as suggested by the applicant.

   [ ] None of the figures.

   [ ] because the applicant failed to suggest a figure.

   [ ] because this figure better characterizes the invention.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00600

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/17 G02B6/16 C03B37/075 C03B37/027

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B C03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 802 236 A (DIGIOVANNI DAVID JOHN ET AL) 1 September 1998 (1998-09-01) figures 1,2,5 column 5, line 6 - line 67 column 6, line 1 - line 67 column 7, line 1 - line 54 ---	1,2,5,6, 8,10,20, 37
A	US 4 551 162 A (HICKS JR JOHN W) 5 November 1985 (1985-11-05) column 3, line 21 - line 68 column 4, line 1 - line 68 column 5, line 1 - line 40 figures 1-7 --- -/--	1,17,20, 37

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 June 2000	29/06/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Mathyssek, K

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/00600

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 520 653 A (HUGHES AIRCRAFT CO) 30 December 1992 (1992-12-30) column 4, line 18 - line 58 column 6, line 51 - line 58 column 7, line 1 - line 58 column 8, line 1 - line 14 figures 1,2,4	1,2,8, 20,37
A	US 3 516 239 A (FUKUDA KENJI ET AL) 23 June 1970 (1970-06-23) column 3, line 12 - line 75 column 4, line 1 - line 65 claims 1,10; figure 1	1,20,37
A	US 4 127 398 A (SINGER JR JOSEPH) 28 November 1978 (1978-11-28) column 7, line 4 - line 68 column 8, line 1 - line 68 column 9, line 1 - line 32 figures 10,12-14	1,20,37
A	US 5 309 540 A (CHARASSE MARIE-NOELLE ET AL) 3 May 1994 (1994-05-03) the whole document	1,20,37

1

INTERNATIONAL SEARCH REPORT

tion on patent family members

[redacted]ational Application No
[redacted]T/GB 00/00600

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5802236 A	01-09-1998	EP 0810453 A	03-12-1997
		JP 10095628 A	14-04-1998
US 4551162 A	05-11-1985	NONE	
EP 0520653 A	30-12-1992	US 5155792 A	13-10-1992
		JP 5264828 A	15-10-1993
US 3516239 A	23-06-1970	DE 1669544 A	16-06-1971
		FR 1518103 A	28-06-1968
		GB 1169106 A	29-10-1969
		NL 6703905 A	18-09-1967
US 4127398 A	28-11-1978	NONE	
US 5309540 A	03-05-1994	FR 2683053 A	30-04-1993
		EP 0540386 A	05-05-1993

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 :
G02B 6/17, 6/16, C03B 37/075, 37/027

A1

(11) International Publication Number: **WO 00/49436**

(43) International Publication Date: 24 August 2000 (24.08.00)

(21) International Application Number: PCT/GB00/00600

(22) International Filing Date: 18 February 2000 (18.02.00)

(30) Priority Data:

9903918.2	19 February 1999 (19.02.99)	GB
9903923.2	19 February 1999 (19.02.99)	GB

(71) Applicant *(for all designated States except US)*: THE UNIVERSITY OF BATH [GB/GB]; Claverton Down, Bath BA2 7AY (GB).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: RUSSELL, Philip, St. John [GB/GB]; Shepherds Mead, Southstoke, Bath BA2 7EB (GB). BIRKS, Timothy, Adam [GB/GB]; 14 Horsecombe Brow, Combe Down, Bath BA2 5QY (GB). KNIGHT, Jonathan, Cave [GB/GB]; Canteen Cottage, Canteen Lane, Wellow, Bath BA2 8PY (GB).

(74) Agents: BARDO, Julian, Eason et al.; Abel & Imray, 20 Red Lion Street, London WC1R 4PQ (GB).

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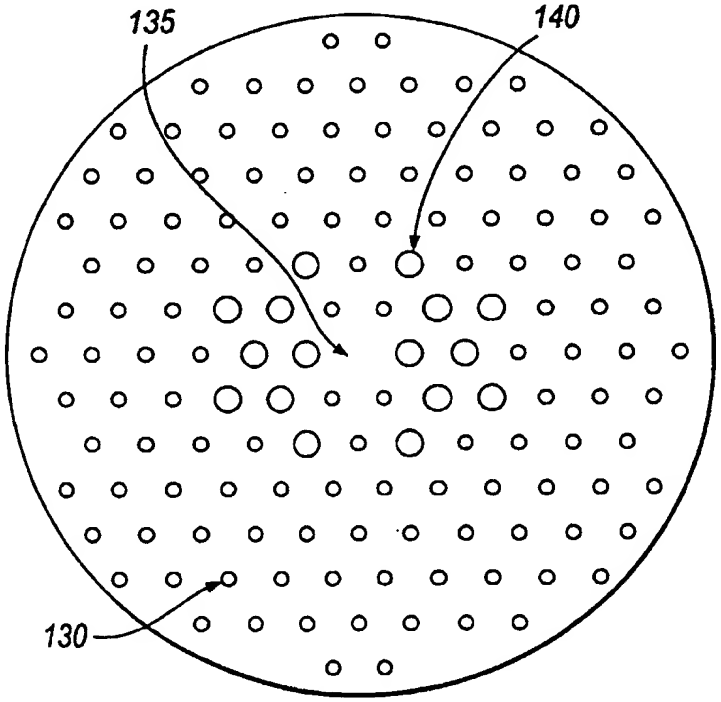
(54) Title: IMPROVEMENTS IN OR RELATING TO PHOTONIC CRYSTAL FIBRES

(57) Abstract

A photonic crystal fibre comprising a bulk material having an arrangement of longitudinal holes (130, 140) and a guiding core (135), wherein the fibre has at-most-two-fold rotational symmetry about a longitudinal axis and as a result of that lack of symmetry, the fibre is birefringent.



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Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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[X] Further documents are listed in the continuation of box C.

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Date of the actual completion of the international search	Date of mailing of the international search report
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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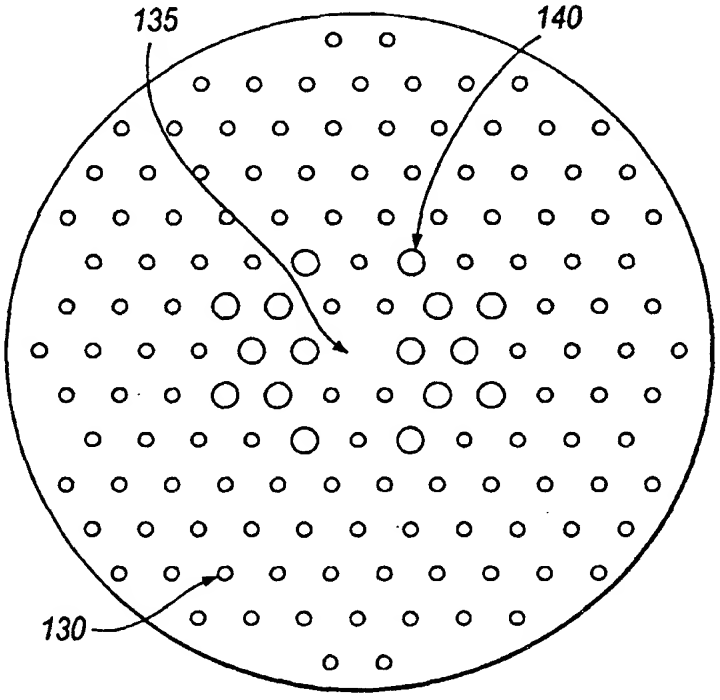

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Improvements in or relating to photonic crystal fibres

This invention relates to photonic crystal fibres and to a method of producing photonic crystal fibres.

A photonic crystal fibre is a special form of optical fibre. Optical fibres are used in many fields including telecommunications, laser machining and welding, laser beam and power delivery, fibre lasers, sensors and medical diagnostics and surgery. They are typically made entirely from solid transparent materials such as glass and each fibre typically has the same cross-sectional structure along its length. The transparent material in one part (usually the middle) of the cross-section has a higher refractive index than the rest and forms an optical core within which light is guided by total internal reflection. We refer to such a fibre as a standard fibre.

Single-mode optical fibres are preferred for many applications because of their superior wave-guiding properties. However, even so-called single-mode optical fibres do not generally offer adequate control over the polarisation of propagating light. A single-mode fibre is so called because it supports only one transverse spatial mode at a frequency of interest, but that spatial mode exists in two polarisation states; that is two degenerate modes that are polarised in orthogonal directions. In real fibres, imperfections will break the degeneracy of those modes and modal birefringence will occur; that is, the mode propagation constant β will be slightly different for each of the orthogonal modes. Because the modal birefringence results from random imperfections, the propagation constants will vary randomly along the fibre. In general, light introduced into the fibre will propagate in both modes and will be coupled from one to the other by small bends and

twists in the fibre. Linearly polarised light will be scrambled into an arbitrary polarisation state as it propagates along the fibre.

In order to maintain the polarisation of a mode in a standard fibre, birefringence can be deliberately introduced into the fibre (so that the effective indices of the two polarisation modes are different) in order to render insignificant the effects of small imperfections. If light is linearly polarised in a direction parallel to one of the optic axes of the fibre then the light will maintain its polarisation. If it is linearly polarised at some other angle, the polarisation will change, as the light propagates down the fibre, from linear to elliptical to linear (not parallel to the starting polarisation) to elliptical and back to linear again, with a period known as the beat length, L_B, where $L_B = \frac{2\pi}{|\beta_x - \beta_y|}$ and β_x and β_y are the propagation constants of the orthogonal modes. That variation is a consequence of a phase difference between two orthogonal components of the mode, which results from the difference in their propagation constants. The shorter the beat length, the more resilient is the fibre to polarisation-scrambling effects. Typically, conventional polarisation-preserving fibre has a beat length of the order of a millimetre. The strength of birefringence can also be represented by the parameter $B = \frac{|\beta_x - \beta_y|}{k_0} = |n_x - n_y|$, where $k_0 = \frac{2\pi}{\lambda}$ (where λ is the wavelength) and n_x and n_y are the refractive indices seen by the orthogonal modes.

In the last few years a non-standard type of optical fibre has been demonstrated, called the photonic-crystal fibre (PCF). Typically, this is made from a single solid,

and substantially transparent, material within which is embedded a periodic array of air holes, running parallel to the fibre axis and extending the full length of the fibre. A defect in the form of a single missing air hole within the regular array forms a region of raised refractive index within which light is guided, in a manner analogous to total-internal-reflection guiding in standard fibres. Another mechanism for guiding light is based on photonic-band-gap effects rather than total internal reflection. Photonic-band-gap guidance can be obtained by suitable design of the array of air holes. Light with particular propagation constants can be confined to the core and will propagate therein.

Photonic-crystal fibre can be fabricated by stacking glass canes, some of which are capillaries on a macroscopic scale, into the required shape, and then holding them in place while fusing them together and drawing them down into a fibre. PCF has unusual properties such as the ability to guide light in a single-mode over a very broad range of wavelengths, and to guide light having a relatively large mode area which remains single-mode.

Birefringence can be produced by several mechanisms. It can be caused by the anisotropic nature of the polarisability of a material; i.e. by anisotropy at an atomic level. It can be caused by the arrangement of elements of a material structure at a scale larger than atomic; that phenomenon is known as form birefringence. It can also be caused by mechanical stress; that phenomenon is known as stress birefringence or the photo-elastic effect. In standard fibres, form birefringence is achieved by changing the shape of the fibre cross-section; for example, by making the core or cladding elliptical. Birefringence in a weakly-guiding fibre is generally rather weak ($B \sim 10^{-6}$).

Stress birefringence can be induced by inserting rods of borosilicate glass on opposite sides of the fibre core in the fibre pre-form. Variation in the location and shape of the borosilicate rods can induce different levels of birefringence. Stress-induced birefringence permits $B \sim 10^{-4}$.

The methods used to produce birefringence in standard fibres, and thus to produce standard polarisation-preserving fibres, are, in general, not directly suitable for use in photonic-crystal fibre.

An object of the invention is to provide a photonic crystal fibre which is birefringent so that the fibre can be used as a polarisation-preserving fibre. Another object of the invention is to provide a method of producing such a fibre.

According to the invention there is provided a photonic crystal fibre comprising a bulk material having an arrangement of longitudinal holes and a guiding core, wherein the fibre has at most-two-fold rotational symmetry about a longitudinal axis (that is any longitudinal axis) and as a result of that lack of symmetry, the fibre is birefringent.

The arrangement of holes may be substantially periodic except for the presence of the core.

Advantageously, the birefringence is such that light with a wavelength of 1.5 microns propagating in the fibre has a beat length of less than 1 cm. More advantageously, the birefringence is such that light with a wavelength of 1.5 microns propagating in the fibre has a beat length of less than 5 mm. More advantageously, the birefringence is such that light with a wavelength of 1.5 microns propagating in the fibre has a beat length of less than 1 mm and preferably less than 0.5 mm; such short beat lengths are not generally obtainable in standard fibres. Of course, a

particular fibre may not guide light at a wavelength of 1.5 microns; in that case, the beat length at a guided wavelength may be readily scaled up or down to an equivalent beat length at 1.5 microns. For example, a beat length of 1mm at a wavelength of 1.55 microns is equivalent to a beat length of 0.41mm at a wavelength of 633nm, and a beat length of 0.5mm at a wavelength of 1.55 microns is equivalent to a beat length of 0.21mm at a wavelength of 633nm.

It will be understood that in a real fibre there will inevitably be minor anomalies in the structure that mean that no fibre has absolute symmetry of any kind; in conventional photonic crystal fibres, however, it is readily apparent that the real fibre does have a considerable amount of rotational symmetry (most commonly six-fold rotational symmetry) and that symmetry is sufficiently strong to make the behaviour of the fibre similar to that of a theoretical fibre having absolute symmetry. In a similar way, where reference is made to a fibre having at-most-two-fold rotational symmetry, it should be understood that not only does the fibre not strictly have any higher symmetry but, furthermore, it does not behave as would a fibre which had a significant amount of higher symmetry.

In its broadest aspect, the invention is concerned with a lack of higher rotational symmetry in any aspect of the fibre. Most typically, the lack of symmetry may arise in some feature of the internal microstructure of the fibre and, commonly, of the arrangement of holes, whilst the overall cross-sectional shape of the fibre may be circular and thus have circular symmetry; it is within the scope of the invention for the arrangement of holes to have more-than-two-fold rotational symmetry but for the fibre to lack more-than-two-fold rotational symmetry in some other sense and examples of such arrangements are given below.

Preferably, the fibre has two-fold rotational symmetry.

Preferably, the rotational symmetry is about an axis passing through the core.

If a fibre has greater than two-fold rotational symmetry then linearly polarised light would have the same propagation constant β when polarised parallel to two or more (not necessarily orthogonal) axes. As is the case in a real fibre with circular symmetry, imperfections in the fibre will result in power transfer between modes polarised parallel to each of those axes. Consequently, light which is initially linearly polarised will excite additional modes and quickly become randomly polarised.

The core may include a hole. The hole may be filled with material other than air. Alternatively, the core may not include a hole.

The arrangement of holes may have at-most-two-fold rotational symmetry parallel to the longitudinal axis of the fibre. Alternatively, the arrangement of holes may have higher-than-two-fold rotational symmetry about an axis parallel to the longitudinal axis of the fibre. The rotational symmetry may be about an axis passing through the core.

The lack of higher rotational symmetry may at least partly result from a variation, across the cross-section of the fibre, in one or more of the following: the microstructure of the core, the diameter of the holes, the bulk material, the material contained in the holes or the shape of the holes. The shape variation may be due to deformation resulting from stresses in the fibre as it is drawn. The lack of higher rotational symmetry may result from a variation across the cross-section of the fibre, in one of the following in combination with one or more of the following or with a variation in another parameter: the

microstructure of the core, the diameter of the holes, the bulk material, the material contained in the holes, the shape of the holes.

The birefringent fibre may have form birefringence and/or stress birefringence. Although form birefringence in standard fibres is not sufficient to give the required short beat length, the potentially much larger refractive index contrast in photonic crystal fibres can result in strong form birefringence. A new effect, not possible with standard fibres, is found when the pattern of stresses within the fibre during the draw process distorts certain of the air holes surrounding the fibre core along one axis, giving additional birefringence.

Also according to the invention, there is provided a method of producing a birefingent photonic crystal fibre, the method comprising the following steps:

(a) forming a stack of canes, at least some of which are capillaries, the stack including canes arranged to form a core region in the fibre and canes arranged to form a cladding region in the fibre; and

(b) drawing the stack of canes into a birefringent fibre, which has at-most-two-fold rotational symmetry about a longitudinal axis.

Birefringence is thus introduced by modification of the method used to fabricate the photonic crystal fibre preform. The modification of the fabrication procedure may consist of the reduction in material symmetry to at-most-two-fold symmetric features in the periodic stack of canes which comprise the preform. Such structures will, in general, change both the shape of the guided mode and the pattern of stresses within the photonic crystal structure.

One way in which birefringence can be introduced is by including in the preform different capillaries at two-fold symmetric pairs of lattice sites. Those inclusions might be placed near to the core so as to alter the shape of the guided mode ("form birefringence") or they might be placed some way from the core but be made of a material with different properties, thus altering the pattern of stresses within the fibre core ("stress birefringence"). The preform may be structured so as to introduce birefringence by forming substantial parts of the fibre preform from a different type of capillary, which again introduces both stress and form birefringence. The basic periodic lattice which forms the waveguide cladding could be a simple close-packed array of capillaries with nominally identical external diameters or it could be an array of capillaries with generally different morphological characteristics, and forming different periodic structures. A square lattice may be formed from capillaries and rods with different diameters. Square and rectangular lattices can be used to build up naturally birefringent crystal structures for the cladding, simplifying the design of polarisation-preserving photonic crystal fibre.

The lack of higher rotational symmetry may at least partly result from variations, across the cross-section of the stack, in the internal diameters of the capillaries, in the material of which the canes are made, in the material with which the capillaries are filled and/or in the external diameter of the canes.

Canes may be provided at the vertices of a cladding lattice which has at-most-two-fold rotational symmetry about the centre of the canes arranged to form the core. Capillaries of selected internal diameters may be provided at the vertices of a cladding lattice which has at-most-two-

fold rotational symmetry about the centre of the canes arranged to form the core, the selected diameters of the capillaries at the vertices of the cladding lattice being different from the diameters of the capillaries at other sites.

A substantial number of cladding canes, near to the canes arranged to form the core, may be different.

Birefringence may at least partly result from stresses formed within the fibre as it is drawn. The stress may be introduced by the inclusion, at sites having at-most-two-fold rotational symmetry, of a cane made from a different material from that of which at least some of the other canes in the lattice are made. The stress may be introduced by the inclusion, at sites having at-most-two-fold rotational symmetry, of capillaries having a different capillary wall thickness from that of at least some of the other capillaries.

The stresses may result in the deformation of holes surrounding the core of the drawn fibre and that deformation may result in birefringence.

The stresses may result in stresses in the core of the drawn fibre and those stresses may result in birefringence.

The lack of higher rotational symmetry may at least partly result from pressurisation and/or evacuation of at least one of the capillaries during the drawing of the stack.

In any of the above-described methods, the rotational symmetry of the stack of canes is preferably two-fold rotational symmetry.

Also according to the invention there is provided a method of producing a photonic crystal fibre, comprising:

(a) providing a plurality of elongate canes, each having a longitudinal axis, a first end and a

second end, at least some of the canes being capillaries each having a hole parallel to the longitudinal axis of the cane and running from the first end of the cane to the second end of the cane;

(b) forming the canes into a stack, the canes being arranged with their longitudinal axes substantially parallel to each other and to the longitudinal axis of the stack;

(c) drawing the stack into a fibre whilst maintaining the hole of at least one capillary in communication with a source of fluid at a first pressure whilst maintaining the pressure around the capillary at a second pressure that is different from the first pressure, wherein the hole at the first pressure becomes, during the drawing process, a size different from that which it would have become without the pressure difference.

In the new method, substantial and controlled changes may occur in the fibre structure while it is being drawn; for example, there may also be controlled expansion of the air holes during the draw. In prior art photonic crystal fibres the required microstructure was created on a macroscopic scale, and then reduced in scale by drawing it into a fibre.

Preferably, the tube surrounds the stack of canes over at least a part of their length and the inside of the tube is maintained at the second pressure.

It will be understood that the phrase "expansion of the air holes" refers to production of air holes of a size (in cross-section taken perpendicularly to the longitudinal axis of the capillaries) greater than that which it would have

been without the pressure difference. In reality, a fibre produced by drawing has a very much smaller total cross-sectional area than the preform (here the stack of canes) from which it is made, and the air holes in the invention will therefore not, in general, "expand" in absolute terms.

Changes during the draw can be thus controlled in two main ways: by use of a pressure differential applied to certain holes, and by enclosing the entire preform, preferably in a tube which is preferably thick walled and may comprise silica and is drawn down with and forms part of the final fibre. Preferably the tube does not undergo deformation significantly different from that which it would undergo without the pressure difference.

Preferably the tube restricts the expansion of at least one of the holes at the first internal pressure.

Preferably the stack of canes has at-most-two-fold rotational symmetry about any of the longitudinal axes. Such a stack may be used in the drawing of a birefringent fibre.

Preferably during the drawing process:

the tube is sealed to a first end of an evacuatable structure and the second end of the tube is within the evacuatable structure;

at least some of the capillaries pass through the evacuatable structure and are sealed to a second end thereof;

and the evacuatable structure is substantially evacuated in order to produce the second internal pressure.

Preferably the evacuatable structure is a metal tube.

By way of example only, an embodiment of the invention will now be described, with reference to the accompanying drawings, of which:

Fig. 1 is a schematic diagram of an example of a standard fibre.

Fig. 2 is a schematic diagram of a conventional photonic-crystal fibre having a high-index core defect.

Fig. 3 is a schematic diagram of a conventional photonic-crystal fibre (a photonic-band-gap fibre) having a low-index core defect.

Fig. 4 is a schematic diagram of a photonic-crystal-fibre preform which has been partially drawn into a fibre.

Fig. 5 is a schematic cross-sectional diagram of a first polarisation-preserving photonic-crystal fibre according to the invention, in which the cladding holes form a rectangular lattice.

Fig. 6 is a schematic cross-sectional diagram of a second polarisation-preserving photonic-crystal fibre according to the invention, in which the pattern of cladding holes near to the core has two-fold symmetry.

Fig. 7 is a schematic cross-sectional diagram of a third polarisation-preserving photonic-crystal fibre according to the invention, in which the pattern of cladding holes far from the core has two-fold symmetry.

Fig. 8 is a schematic cross-sectional diagram of a fourth polarisation-preserving photonic-crystal fibre according to the invention, in which the pattern of dielectric inclusions in the cores of the lattice has two-fold symmetry.

Fig. 9 is a schematic cross-sectional diagram of an arrangement of canes for forming a photonic crystal fibre having a square lattice.

Fig. 10 is a schematic cross-sectional diagram of a portion of a photonic crystal fibre having a square lattice of holes each having one of two different diameters.

Fig. 11 shows a photonic crystal fibre having a square lattice.

Fig. 12 shows canes forming part of a stack for forming a photonic crystal fibre.

Fig. 13 shows a photonic crystal fibre formed from a stack such as that shown in Fig. 12.

Fig. 14 shows schematically a stack of capillaries suitable for use in a further method according to the invention;

Fig. 15 shows schematically apparatus used with the stack of Fig. 14;

Fig. 16a shows the cleaved end face of a photonic crystal fibre made from a preform similar to that of Fig. 14 and with the apparatus of Fig. 15;

Fig. 16b shows a detail of the structure near the core of the fibre of Fig. 16a;

Fig. 17a shows a highly birefringent fibre made with the apparatus of Fig. 15;

Fig. 17b shows polarisation beating observed at a wavelength of 1550nm in the fibre of Fig. 17a.

Standard fibres, such as the example shown in Fig. 1, in their simplest form comprise essentially a cylindrical core 10 and concentric cylindrical cladding 20. Typically, both the core and the cladding will be made of the same material, usually silica, but each is doped with other materials in order to raise the refractive index of the core 10 and lower the refractive index of the cladding 20. Light, of appropriate wavelengths, is confined to the core 10, and guided therein, by total internal reflection at the core-cladding boundary 15.

A typical photonic crystal fibre, shown in Fig. 2, comprises a cylinder of transparent bulk material 30 (e.g.

silica) with a lattice of cylindrical holes 40, which run along its length. The holes are arranged at the vertices and centres of regular hexagons, which have six-fold rotational symmetry. The holes have a regular period, broken by the omission of one hole near the centre of the fibre. The region 50 of the fibre surrounding the site of the missing hole has the refractive index of the bulk material 30. The refractive index of the remainder of the fibre is attributable to the refractive index of both the bulk material 30 and the air in the holes 40. The refractive index of air is lower than that of, for example, silica and, consequently, the 'effective refractive index' of the material with the holes is lower than that of the region 50 surrounding the missing hole. The fibre can therefore confine light approximately to the region 50, in a manner analogous to waveguiding by total internal reflection in standard fibres. The region 50 is therefore referred to as the 'core' of the photonic crystal fibre.

In another form of photonic crystal fibre, photonic band gap guidance acts to confine light to the fibre 'core'. In the example of such a fibre shown in Fig. 3, there is a matrix of holes 70 in bulk material 30. The holes are arranged at the vertices (but not the centres, cf. Fig. 2) of regular hexagons, which have six-fold rotational symmetry. The regularity of the matrix is again broken by a defect, but it is, in the illustrated example, an additional hole 60 at the centre of one of the lattice hexagons, that hexagon being near the centre of the fibre. The area surrounding the additional hole 60 can again be referred to as the core of the fibre. Disregarding (for the moment) hole 60, the periodicity of holes in the fibre results in there being a band-gap in the propagation constants of light which can propagate in the fibre. The addition of hole 60

effectively creates a region with a different periodicity, and that region can support propagation constants different from those supported in the rest of the fibre. If some of the propagation constants supported in the region of hole 60 fall within the band-gap of propagation constants forbidden in the rest of the fibre then light with those propagation constants will be confined to the core and propagate therein. Note that because the hole 60 is a low-index defect (it results in air being where bulk material would otherwise be), total internal reflection effects are not responsible for that waveguiding in the illustrated example.

Photonic crystal fibres can be manufactured by a process, one stage of which is shown in Fig. 4. In the first stages of that process (not shown), a cylinder of bulk material (e.g. silica), is milled so that it has a hexagonal cross-section, and a hole is drilled along its centre. The rod is then drawn into a cane using a fibre drawing tower. The cane is cut into lengths and the resulting, short canes 80 are stacked to form an array of canes, as shown in Fig. 4. The cane 100 at the centre of the illustrated array is not a capillary; i.e., it has no hole; the illustrated array will form an effective-index guidance type of fibre. The array of canes 80 is fused together and then drawn into the final photonic crystal fibre 110.

The fibre shown in Fig. 5 has a lattice 120 of holes, which are arranged at the vertices of rectangles, which are not squares. The periodicity of the lattice is broken by the omission of a hole in the region 125 near the centre of the fibre cross-section. The centre-to-centre spacing (pitch) of the holes is different parallel to axis x (pitch Λ_x) from the pitch (Λ_y) parallel to axis y. The fibre shown in Fig. 5 could be manufactured using a cane which is milled to have a rectangular cross-section. The lattice of Fig. 5

has two-fold rotational symmetry and will therefore be birefringent.

Figs. 6 and 7 show photonic crystal fibres which are effective-index-guidance fibres having a hexagonal lattice similar to that of the fibre of Fig. 2. Such lattices are not intrinsically birefringent. However, in the lattices of Fig. 6 and 7, holes 140 are of a larger diameter than holes 130. That anisotropy in the lattice creates a two-fold rotationally symmetric pattern of holes about the region 135 where a hole is missing from the lattice.

The pattern of large holes 140 in Fig. 6 has an effect analogous to that of form birefringence in a standard fibre. The variation of hole diameter near to the 'core' 135 directly creates a variation in the effective index seen by a guided mode.

The pattern of large holes 140 in Fig. 7 produces stresses in the core which cause birefringence in the same way that birefringence is caused in standard fibres. A new effect, not possible with standard fibres, is that the pattern of stresses within the fibre can, during the draw process, distort some of the air holes surrounding the fibre core 135 along one axis, giving additional birefringence.

Another alternative, illustrated in Fig. 8, is for some of the holes 150 to be filled with material other than air (so that they have a different dielectric constant). Again, the six-fold rotational symmetry of the lattice is reduced to a two-fold rotational symmetry.

The stack of canes shown in Fig. 9 are of three types: large diameter canes 160 which are capillaries, small diameter solid canes 170 and a large diameter solid cane 180. The canes are arranged so that the large diameter canes 160 form a square lattice, which is broken by a defect at a central site, the defect being the large diameter solid

cane 180. Interstitial gaps, resulting from the non-tesselating nature of the circular cross-sections of canes 160, are filled by small diameter canes 170.

A photonic crystal fibre having two-fold symmetry is shown in Fig. 10. The fibre has a lattice structure which can be constructed from a stack of canes arranged in a manner similar to the stack of Fig. 9. Solid cane 180 results in a defect similar to defect 210. In this case, however, alternate rows of holes (190, 200) have large and small diameters respectively. Such an effect could be achieved with the lattice of Fig. 9 by providing alternate rows of canes 160 with large and small internal diameters (but with constant external diameters).

The fibre of Fig. 11 can be seen to have approximately a square lattice such as might be produced from the stack of Fig. 9.

Fig. 12 shows a stack of canes 220 which are capillaries. The canes are arranged on an hexagonal lattice, with the periodicity of the structure broken by a solid cane 240. It will be noted that a row of canes about half-way up the photograph are capillaries with thicker walls 250 than the walls 230 of other capillaries. When a fibre is drawn from the stack of canes, such an arrangement will result in a fibre, such as that shown in Fig. 13, having a row of holes 260 having a smaller diameter than other holes in the fibre.

Many other patterns of capillaries and canes, varying in various parameters, could be envisaged that would fall within the scope of the invention.

Another method of making a fibre is illustrated in figs. 14 and 15. A stack of a regular array of capillaries 300 are placed inside a thick-walled silica glass tube 310 (Fig. 14). The silica glass tube 310 forms part of the

fibre after drawing, serving as a jacket to provide mechanical strength. During the drawing process (Fig. 15), the inside of the tube 310 is evacuated by sealing it within an evacuatable structure while the inside of some or all of the capillaries 300 are kept at a different and higher pressure, for example, because they are left open to the atmosphere.

The evacuatable structure is a brass cylinder 320. Initially it is open at both ends. The cylinder is then sealed to the tube 310 at one end. The tube terminates within the brass cylinder 320. Some or all of the capillaries 300 pass right through the brass cylinder 320, which is then sealed around those capillaries that pass right through the cylinder at the top. The brass cylinder 320 is evacuated during the drawing process.

During the drawing process, in which the tube 310 and the capillaries 300 are drawn downwardly from the brass tube, the outer tube 310 does not collapse, despite being evacuated, because it has thick walls. In contrast, interstitial holes between capillaries 300 which are already smaller and have relatively thin boundaries defined by walls of the capillaries quickly collapse and are not present in the final fibre (which is desirable). Capillaries which are evacuated will also collapse completely if there is a higher pressure around the capillary. On the other hand capillaries which are filled with atmospheric-pressure air expand.

By adopting the method just described it is possible to form very regular and thin-walled structures and to make fibres with very small guiding cores. Fig. 16 shows such a fibre which has an outer cladding 330 comprising the tube 310 after drawing and an inner cladding 340 comprising the capillaries 300. The inner cladding is of approximately

10μm radius and comprises a honeycomb structure of expanded holes. The holes surround a guiding core 350 that is of approximately 1μm diameter and has been formed from an elongate cane that is not a capillary. It will be appreciated that the fibre shown in Fig. 16 is made by having all the capillaries 300 passing right through the cylinder 320 and has substantial multi-fold rotational symmetry; thus the fibre is not substantially birefringent.

In contrast Fig. 17a shows a fibre that is made to be highly birefringent by stacking thicker-walled capillaries at certain sites; smaller air holes 360 are formed at those sites. An alternative method of producing the fibre might be by having four selected capillaries terminating within the cylinder 320; the holes in those selected capillaries 300 would not expand during drawing and would thereby provide the four small holes 360. The fibre of Fig. 17a is highly birefringent because it has only two-fold symmetry resulting from the four smaller holes 360 lying along a diameter of the inner cladding, either side of the core.

Fig. 17b shows the polarisation beating data of the fibre of Fig. 17a. From the data, the beat length of the fibre can be shown to be 0.92mm at a wavelength of 1550nm; such a beat length is sufficiently short for the fibre to act as a polarisation-maintaining, single mode photonic crystal fibre.

CLAIMS

1. A photonic crystal fibre comprising a bulk material having an arrangement of longitudinal holes and a guiding core, wherein the fibre has at-most-two-fold rotational symmetry about a longitudinal axis and as a result of that lack of symmetry, the fibre is birefringent.
2. A photonic crystal fibre as claimed in claim 1, in which the arrangement of holes is substantially periodic except for the presence of the core.
3. A photonic crystal fibre as claimed in claim 1 or claim 2, in which the birefringence is such that light with a wavelength of 1.5 microns propagating in the fibre has a beat length of less than 5 mm.
4. A photonic crystal fibre as claimed in any preceding claim, in which the fibre has two-fold rotational symmetry.
5. A photonic crystal fibre as claimed in any preceding claim, in which the rotational symmetry is about an axis passing through the core.
6. A photonic crystal fibre as claimed in any of claims 1 to 5, in which the core includes a hole.
7. A photonic crystal fibre as claimed in claim 6, in which the hole is filled with material other than air.
8. A photonic crystal fibre as claimed in any of claims 1 to 5, in which the core does not include a hole.
9. A photonic crystal fibre as claimed in any preceding claim, in which the arrangement of holes has at-most-two-fold rotational symmetry about an

axis parallel to the longitudinal axis of the fibre.

10. A photonic crystal fibre as claimed in any of claims 1 to 8, in which the arrangement of holes has higher-than-two-fold rotational symmetry about an axis parallel to the longitudinal axis of the fibre.

11. A photonic crystal fibre as claimed in any preceding claim, in which the lack of higher rotational symmetry at least partly results from a variation, across the cross-section of the fibre, in the microstructure of the core.

12. A photonic crystal fibre as claimed in any preceding claim, in which the lack of higher rotational symmetry at least partly results from a variation, across the cross-section of the fibre, in the diameter of the holes.

13. A photonic crystal fibre as claimed in any preceding claim, in which the lack of higher rotational symmetry at least partly results from a variation, across the cross-section of the fibre, in the bulk material.

14. A photonic crystal fibre as claimed in any preceding claim, in which the lack of higher rotational symmetry at least partly results from a variation, across the cross-section of the fibre, in the material contained in the holes.

15. A photonic crystal fibre as claimed in any preceding claim, in which the lack of higher rotational symmetry at least partly results from a variation, across the cross-section of the fibre, in the shape of the holes.

16. A photonic crystal fibre as claimed in claim 15, in which the shape variation is due to deformation resulting from stresses in the fibre as it is drawn.

17. A photonic crystal fibre as claimed in any preceding claim, in which the lack of higher rotational symmetry results from a variation across the cross-section of the fibre, in one of the following in combination with one or more of the following or with a variation in another parameter: the microstructure of the core, the diameter of the holes, the bulk material, the material contained in the holes, the shape of the holes.

18. A photonic crystal fibre as claimed in any preceding claim, in which the birefringent fibre has form birefringence.

19. A photonic crystal fibre as claimed in any preceding claim, in which the birefringent fibre has stress birefringence.

20. A method of producing a birefringent photonic crystal fibre, the method comprising the following steps:

(a) forming a stack of canes, at least some of which are capillaries, the stack including canes arranged to form a core region in the fibre and canes arranged to form a cladding region in the fibre; and

(b) drawing the stack of canes into a birefringent fibre which has at-most-two-fold rotational symmetry about any longitudinal axis.

21. A method as claimed in claim 20, in which the stack of canes is arranged to have at-most-two-fold rotational symmetry about a longitudinal axis of the stack.

22. A method as claimed in claim 20 or 21, in which the lack of higher rotational symmetry at least partly results from variations, across the cross-section of the stack, in the internal diameters of the capillaries.

23. A method as claimed in any of claims 20 to 22, in which the lack of higher rotational symmetry at least partly results from variations, across the cross-section of the stack, in the material of which the canes are made.

24. A method as claimed in any of claims 20 to 23, in which the lack of higher rotational symmetry at least partly results from variations, across the cross-section of the stack, in the material with which the capillaries are filled.

25. A method as claimed in any of claims 20 to 24, in which the lack of higher rotational symmetry at least partly results from variations, across the cross-section of the stack, in the external diameter of the canes.

26. A method as claimed in any of claims 20 to 25, in which canes are provided at the vertices of a cladding lattice which has at-most-two-fold rotational symmetry about the centre of the canes arranged to form the core.

27. A method as claimed in any of claims 20 to 25, in which capillaries of selected internal diameters are provided at the vertices of a cladding lattice which has at-most-two-fold rotational symmetry

about the centre of the canes arranged form the core, the selected internal diameters of the capillaries at the vertices of the cladding lattice being different from the internal diameters of the capillaries at other sites.

28. A method as claimed in any of claims 20 to 27, in which a substantial number of cladding canes, near to the canes arranged to form the core, are different from a substantial number of cladding canes, far from the canes arranged to form the core.

29. A method as claimed in any of claims 20 to 28, in which the birefringence results at least partly from stresses formed within the fibre as it is drawn.

30. A method as claimed in claim 29, in which the stress is introduced by the inclusion, at sites having at-most-two-fold rotational symmetry, of a cane made from a different material from that of which at least some of the other canes in the lattice are made.

31. A method as claimed in claim 29, in which the stress is introduced by the inclusion, at sites having at-most-two-fold rotational symmetry, of capillaries having a different capillary wall thickness from that of at least some of the other capillaries.

32. A method as claimed in any of claims 29 to 31 in which the stresses result in the deformation of holes surrounding the core of the drawn fibre and that deformation results in birefringence.

33. A method as claimed in any of claims 29 to 31 in which the stresses result in stresses in the core

of the drawn fibre, and those stresses result in birefringence.

34. A method as claimed in any of claims 20 to 33, in which the lack of rotational symmetry at least partly results from pressurisation of at least one of the capillaries during the drawing of the stack.

35. A method as claimed in any of claims 20 to 34, in which the lack of rotational symmetry at least partly results from evacuation of at least one of the capillaries during the drawing of the stack.

36. A method as claimed in any of claims 20 to 35, in which the rotational symmetry of the stack of canes is two-fold rotational symmetry.

37. A method of producing a photonic crystal fibre, comprising:

(a) providing a plurality of elongate canes, each having a longitudinal axis, a first end and a second end, at least some of the canes being capillaries each having a hole parallel to the longitudinal axis of the cane and running from the first end of the cane to the second end of the cane;

(b) forming the canes into a stack, the canes being arranged with their longitudinal axes substantially parallel to each other and to the longitudinal axis of the stack;

(c) drawing the stack into a fibre whilst maintaining the hole of at least one capillary in communication with a source of fluid at a first pressure whilst maintaining the pressure around the capillary at a second pressure that is different from the first pressure, wherein the hole at the first

pressure becomes, during the drawing process, a size different from that which it would have become without the pressure difference.

38. A method as claimed in claim 27, in which a tube surrounds the stack of canes over at least a part of their length and the inside of the tube is maintained at the second pressure.

39. A method as claimed in claim 38, in which the tube restricts the expansion of at least one of the holes at the first internal pressure.

40. A method as claimed in any of claims 37 to 39, in which the tube does not undergo deformation significantly different from that which it would undergo without the pressure difference.

41. A method as claimed in any of claims 37 to 40, in which, during the drawing process:

the tube is sealed near to the first end to a first end of an evacuatable structure and the second end of the tube is within the evacuatable structure;

at least some of the capillaries pass through the evacuatable structure and are sealed to a second end thereof;

and the evacuatable structure is substantially evacuated in order to produce the second internal pressure.

42. A method as claimed in claim 41, in which the evacuatable structure is a metal tube.

43. A method as claimed in any of claims 37 to 42, in which the stack of canes has at-most-two-fold rotational symmetry about any of the longitudinal axes.

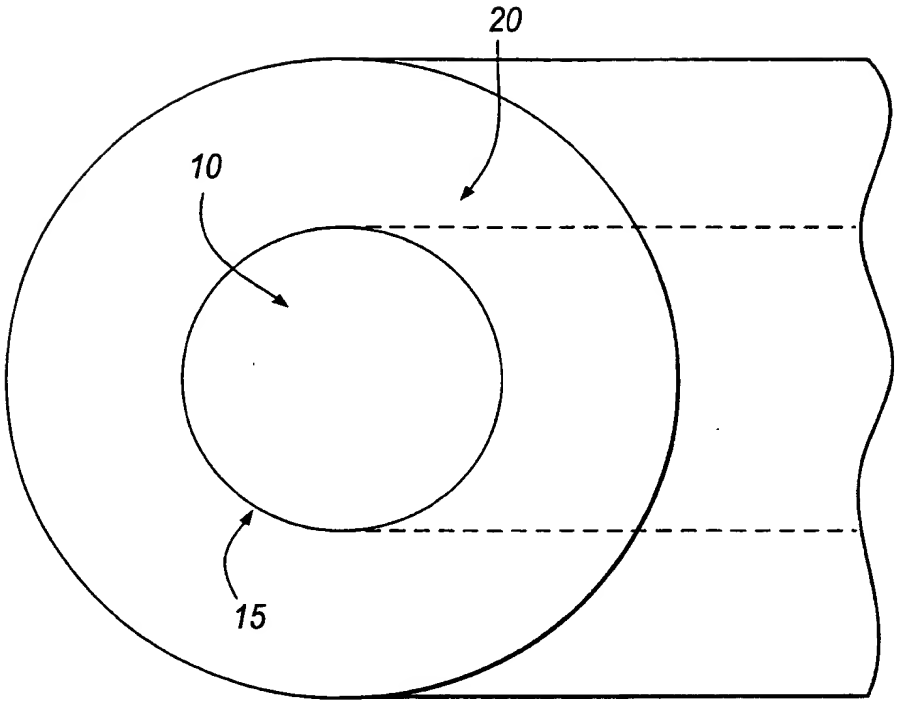

Fig.1

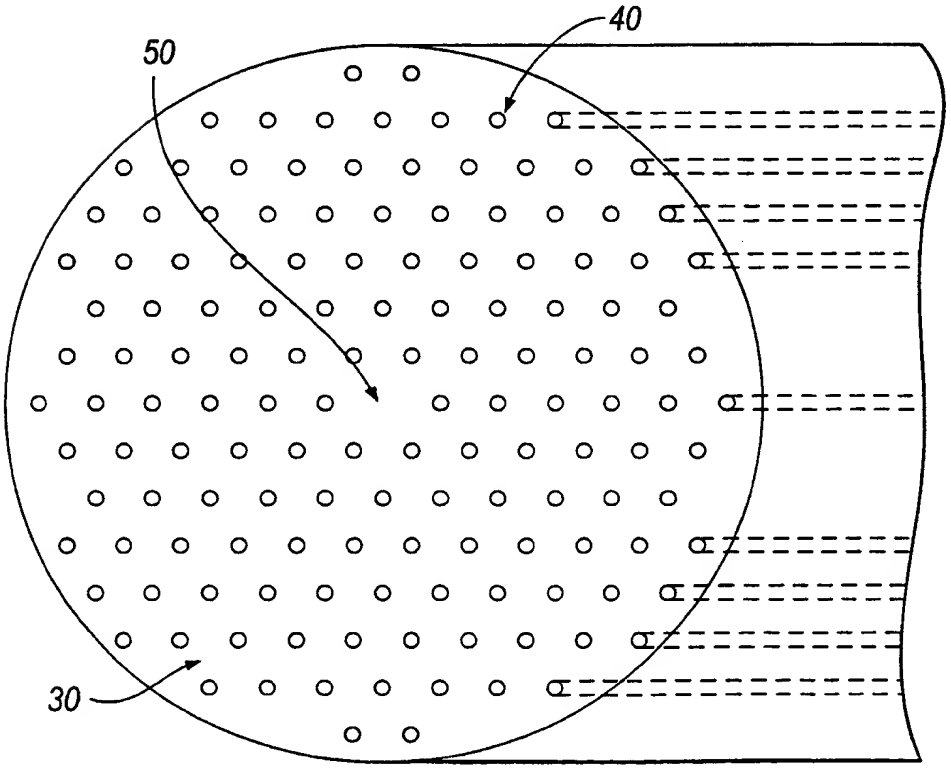

Fig.2

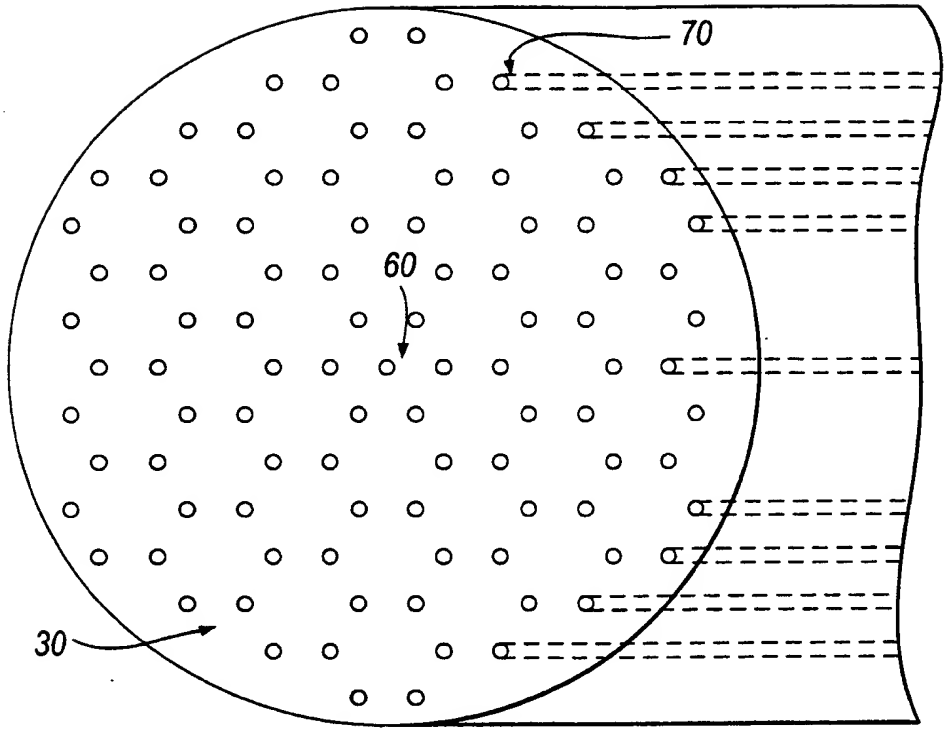

Fig.3

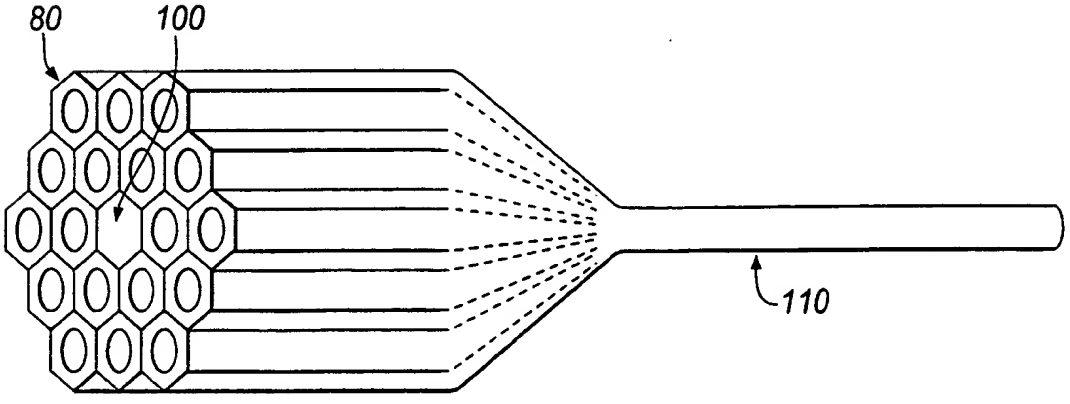

Fig.4

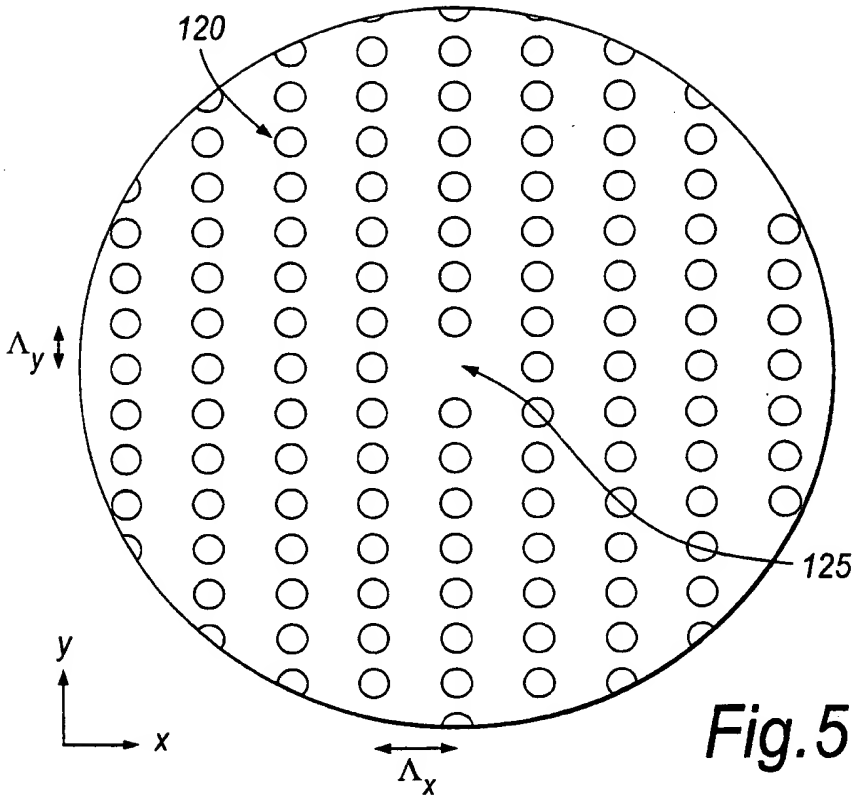

Fig.5

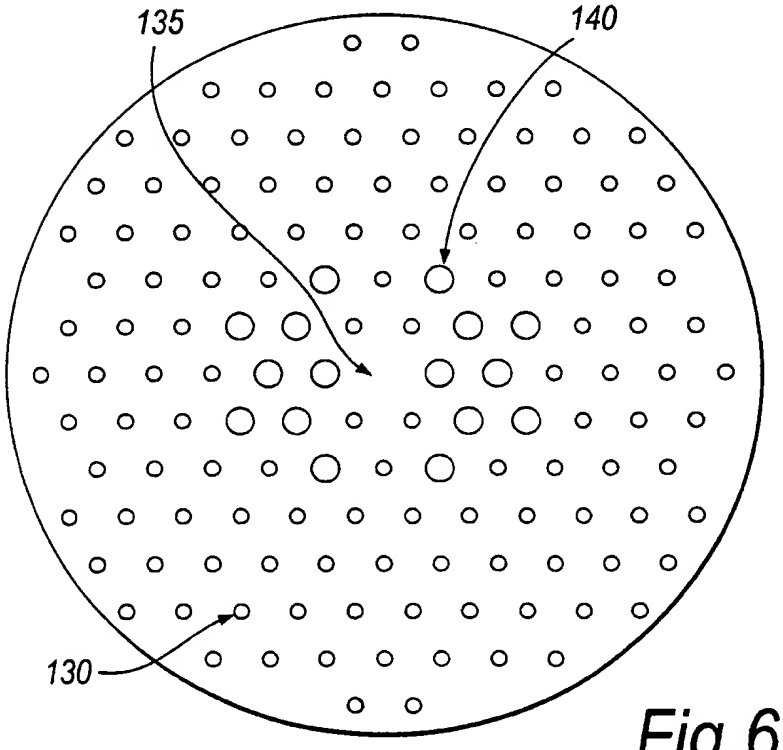

Fig.6

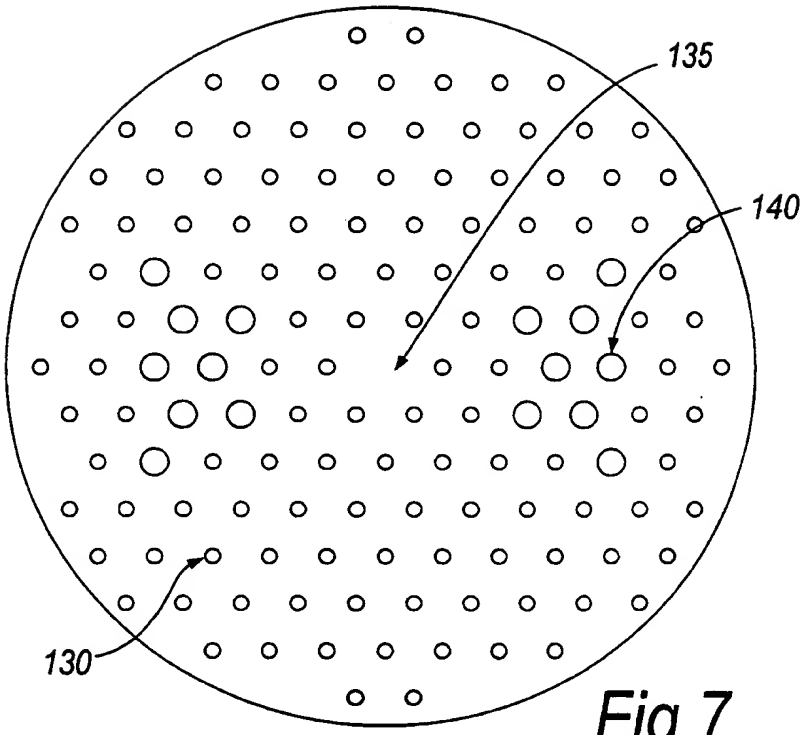

Fig.7

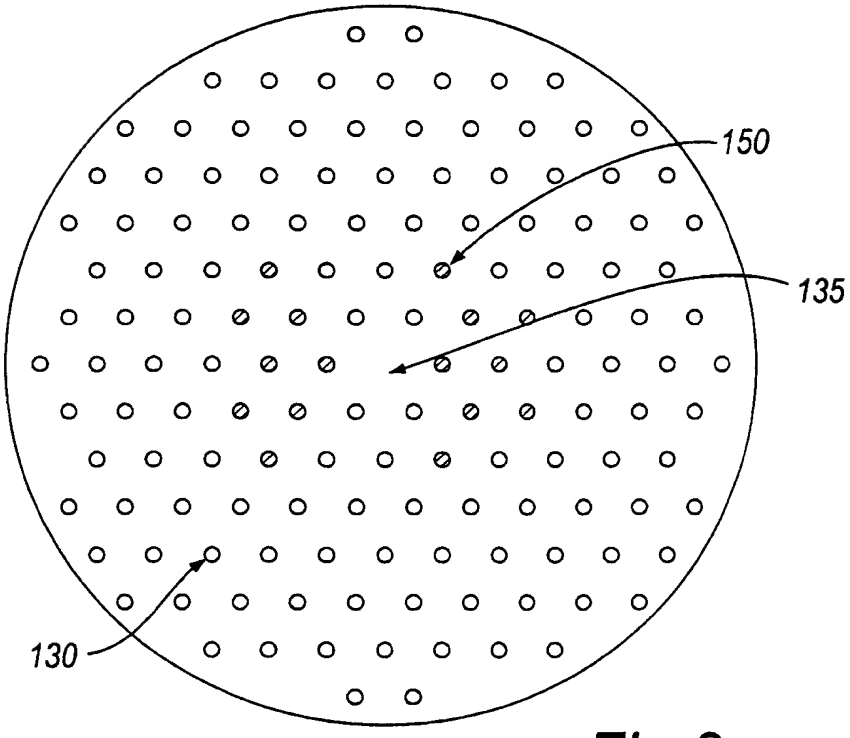

Fig.8

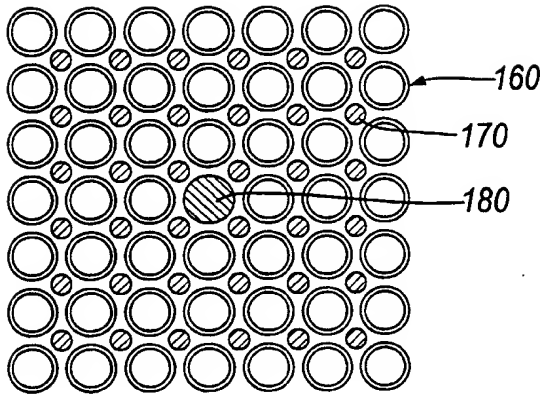

Fig.9

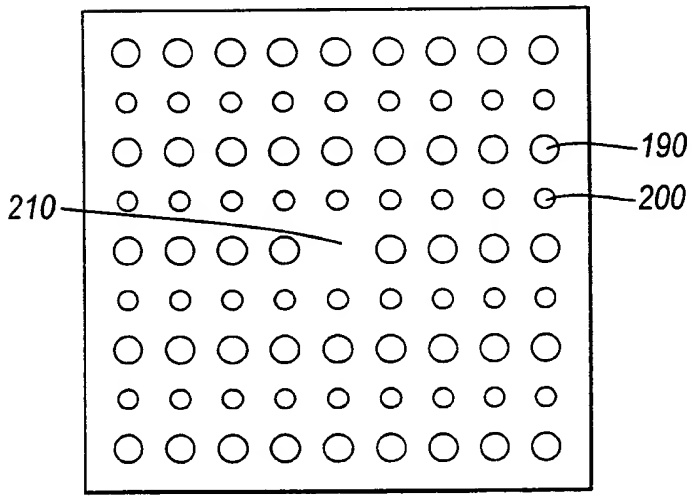

Fig.10

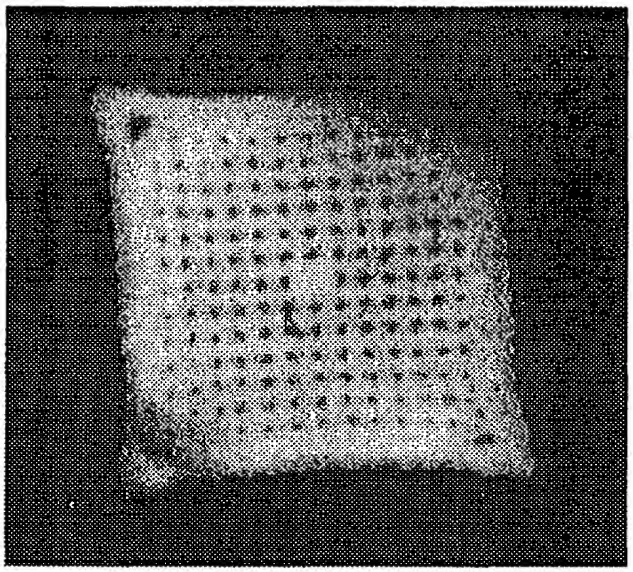

Fig.11

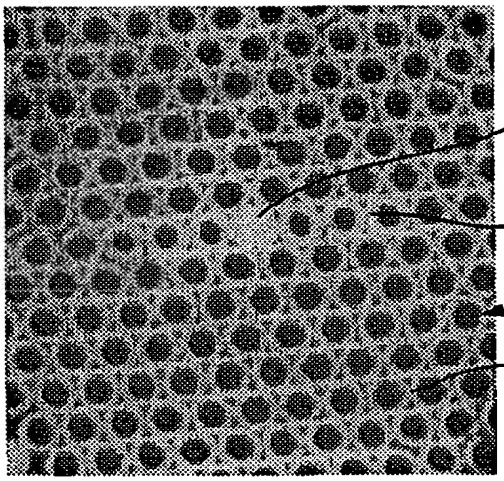

Fig.12

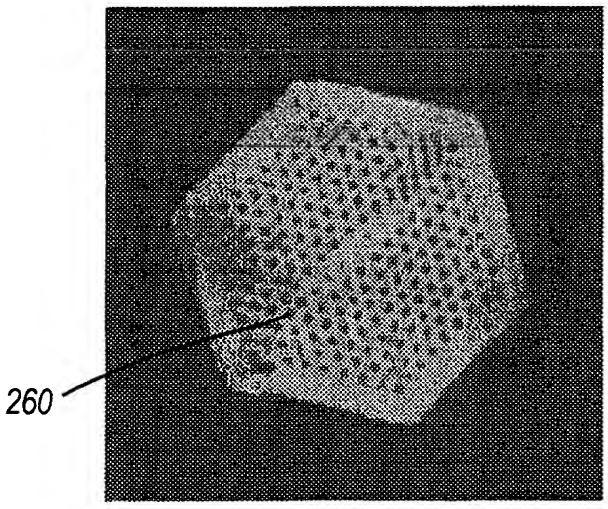

Fig.13

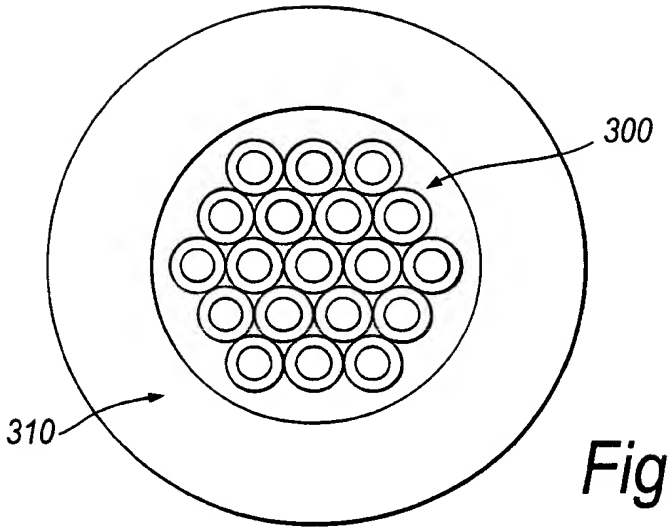

Fig.14

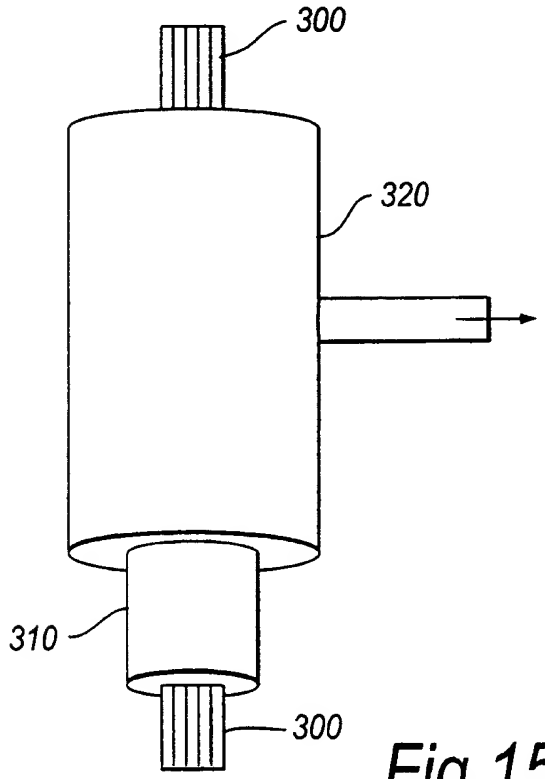

Fig.15

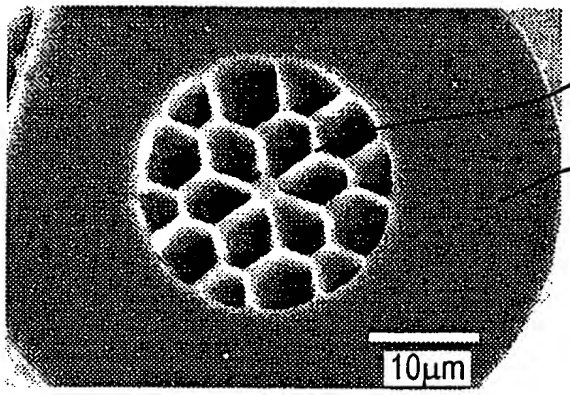

Fig.16(a)

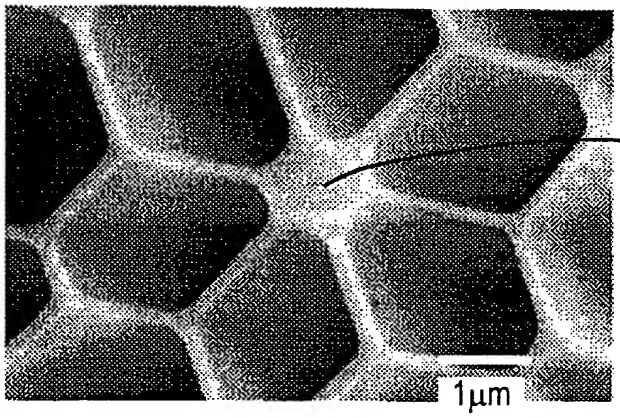

Fig.16(b)

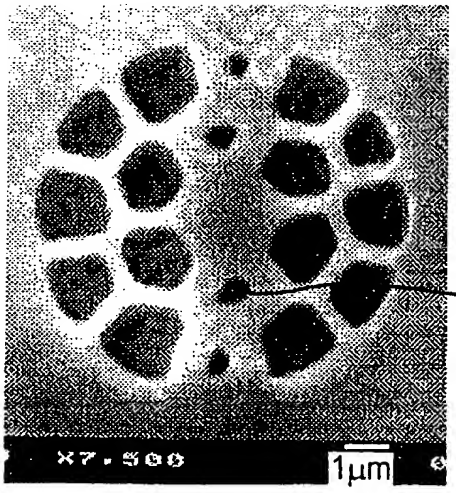

Fig.17(a)

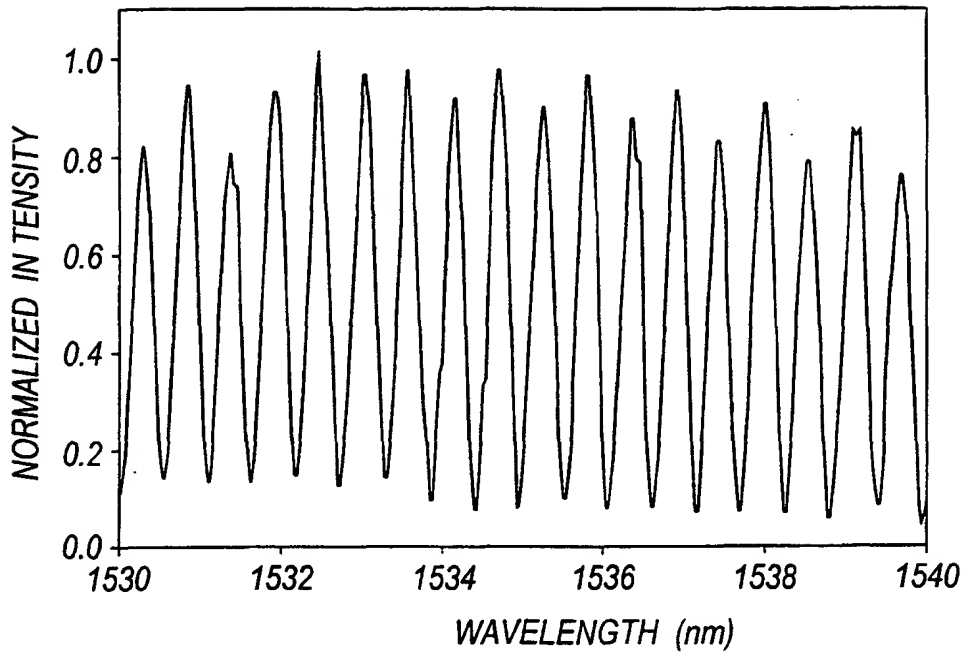
NORMALIZED IN TENSITY
1.0
0.8
0.6
0.4
0.2
0.0
1530
1532
1534
1536
1538
1540
WAVELENGTH (nm)

Fig.17(b)

INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/GB 00/00600

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G02B6/17 G02B6/16 C03B37/075 C03B37/027

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G02B C03B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 802 236 A (DIGIOVANNI DAVID JOHN ET AL) 1 September 1998 (1998-09-01) figures 1,2,5 column 5, line 6 - line 67 column 6, line 1 - line 67 column 7, line 1 - line 54	1,2,5,6, 8,10,20, 37
A	US 4 551 162 A (HICKS JR JOHN W) 5 November 1985 (1985-11-05) column 3, line 21 - line 68 column 4, line 1 - line 68 column 5, line 1 - line 40 figures 1-7	1,17,20, 37

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 June 2000	29/06/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Mathyssek, K

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INTERNATIONAL SEARCH REPORT

Inte onal Application No
PCT/GB 00/00600

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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Inte ional Application No
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